CHAPTER 1
INTRODUCTION

1.1 Background

The merging of telecommunication and computer technologies has led to the high demand of data communications to support various services such as Internet, Integrated Services Digital Network (ISDN) and Broadband-ISDN. These services require high quality of data transmissions with more efficiency and more reliability. Satellite communication systems employing radiowave above 10 GHz can be valuable to tropospheric impairments such as attenuation, depolarization, and interference, that may deteriorate a satellite link. At frequency above 10 GHz, attenuation due to rain is one of the most critical factors to the system design to maintain an availability of communication links throughout the period of service. To design satellite transmission systems to support these various services, various satellite parameters (e.g., link availability, margin) need to be determined.

In recent years, an increasing demand of satellite capacity around the world to support the new services has led to a scarcity of bandwidth for satellite and required the use of higher frequencies i.e. Ku (14/12GHz) and Ka (30/20GHz) bands. In the tropical regions, attenuation due to rain is one of the most critical factors for the satellite link design. To maintain the reliability of satellite link, there is a need to provide suitable compensation techniques such as fade counter-measure and site-diversity. The challenging problem in satellite system design is how much link margin is sufficient and/or what compensation schemes should be provided, given the constraints that the system should be the most economic and the most efficient one.

Rain attenuation statistics, both long-term and short-term statistics, are needed to be well understood to design reliable and cost effective system. Long-term statistics such as a cumulative attenuation distribution is a useful information to design a reliable communication system above 10 GHz. Therefore, system design needs to know how often and how long attenuation will be occurred and persisted for some percentage time of a given year.

Short-term statistics i.e., fade duration distribution especially for fade of less than 10 seconds, is essential for the system design to meet the design criteria of the International Telecommunication Union (ITU-T) for new, high quality data transmission services. For example, the ITU-T G 821 [1980] and ITU-T G-826 [1994] define the unavailable time when the link outage (BER $<10^{-3}$) occurs more than 10 consecutive seconds. Thus, the knowledge of a distribution of fade-duration is essential for the new satellite system design.

The nature of rain affecting on microwave frequencies has been known before the World War II. From the previous studies, most of rain attenuation studies were mainly carried out in the temperate regions but only a few studies were conducted in the tropics. Many studies found that the characteristics of rainfall in the tropics are significantly different from the temperate climates. Studies of rain attenuation in many temperate regions can not successfully be applied to many tropical regions.

Attenuation due to rain in the tropical of Southeast Asia is relatively high compared with other regions. Recently, intensive studies of rain attenuation in Southeast Asia to understand rainfall and rain attenuation characteristics are rarely performed. Due to the lack of these knowledge in this region, it is difficult to design the most reliable and cost-effective Ku-band satellite systems for this region.

Recently, many regional communication satellites, i.e., THAICOM, MEASAT, PALAPA, have been operated the Ku-band (14/12GHz) satellite services. However, the successful design of the satellite links is still questionable. In designing of the Ku-band satellite link, It is not sufficient to provide just only a relatively high link margin to compensate the rain attenuation at a very small percentage time (e.g., 0.01% of the year). Moreover, some satellite services, i.e. Very small aperture terminal (VSAT) system, have the limitation on the transmitted power and it cannot provide such a high link margin to mitigate rain attenuation. Therefore, the need to understand rain attenuation characteristics from an intensive analysis of measured attenuation data and rainfall for a long period of time is essential. In addition, in the area of long-term attenuation statistics cannot be supported, the prediction model developed from the data analysis is essential for the satellite system design. *For this reason, the need to conduct the intensive study of rain attenuation and rainfall in Southeast Asia must be urgently performed.*

1.2 Problems Statement

In order to design more reliable and cost-effective Ku-band satellite system for fixed and broadcasting satellite services, the long-term statistics (e.g., cumulative attenuation distribution, rainfall distribution, worst month distribution, seasonal variation) and short-term statistics (e.g., fade duration, rainfall duration, diurnal variation of rain attenuation) must be clearly understood.

Rain attenuation statistics can be obtained by a beacon method, a radiometric method and a radar method. Both beacon and radiometer are widely used in today's rain attenuation studies. The radiometer is easy to operate, but low measurement ranges only up to 10-12 dB. Beacon can measure attenuation up to 30 dB, but it needs more careful measurement at relatively low attenuation less than 3 dB due to levels fluctuation. Radar may be the best tool for observing the spatial variation of rainstorm for both horizontal and vertical structures, but it needs high investment cost.

In areas where measured attenuation statistics is not available, statistics of rainfall can be used to predict rain attenuation statistics. Cumulative distribution of rainfall rate can be obtained by a well-calibrated rain gauge. Some long-term rainfall statistics may be received at the meteorological services. The behavior of rainfall is more complex and changes from space and time; hence, most of today's rain attenuation prediction models are mainly derived from rainfall rate statistics in the areas of interest. The model of rain attenuation prediction along the propagation path can be established by applying a specific attenuation (an amount of attenuation in one kilometer) associated with some propagation path factors. The specific attenuation can be calculated by knowing raindrop size distribution, raindrop's temperature, terminal velocity of raindrop, frequencies used, polarization etc.

The development of the attenuation model along the earth-satellite path is the main concern in today's radiowave propagation studies. Many well-known prediction models, that work well in the temperate regions i.e., ITU-R 618-2 [1994], tends to be underestimated rain attenuation when applied to the tropical regions. It is due to the difference of rainfall characteristics between the temperate and the tropical climates as well as the lack of experimental data in the tropics to verify the prediction models.

In Southeast Asia, recent studies of rainfall and rain attenuation on Ku-band earth-space paths such as: K. S. McCormick, R. Lekkla, J. Wacha, W.T. Wean [1996], M. Juy, R. Maurel, and M. Rooryck [1990]. G. Brussaard, J DijK [1993], R. Lekkla, P. Prapinmongkolkarn, and P. Hetrakul, N Yoothanorm [1993], R. Lekkla, S.L. Lim, J Wacha, K.S. McCormick [1995], N. Yoothanom, P. Prapinmonkolkarn, P. Takaput, T. Angkeaw and R. Lekkla [1997], found severe rain attenuation in Southeast Asia compared with other temperate regions.

During 1992 - 1995, the joint-cooperation between some ASEAN Countries (Indonesia, Singapore, and Thailand) and Canada to study rain attenuation at Ku-band frequencies for satellite communication in Southeast Asia was reported in the final report entitled "Canada-ASEAN Cooperation in the Ku-band Propagation Measurement Program on Earth-space Path" by K. S. McCormick et al., [1996]. In that cooperation, the Communications Authority of Thailand (CAT) was assigned to be the project coordinator and the Department of Electrical Engineering, Faculty of Engineering, Chulalongkorn University was selected by the CAT to extend further studies of rain attenuation entitled " Analysis on Effects of Rain Attenuation to Ku-band Signals at Low Elevation Angle in Thailand". Results of the study was reported by N. Yoothanorm, et al., [1997].

The studies of rain attenuation by the joint-cooperation between Canada and ASEAN mainly performed on the experimental basis, but extensive statistical analysis of data to obtain the knowledge of rain attenuation and rain intensity behaviors in Southeast Asia were not performed. Therefore, it is the main objective of this research is to further analyze the data collected in Southeast Asia and use the knowledge of rain attenuation to develop a powerful prediction model suitable for Southeast Asia and may apply to other regions as well.

1.3 Research Objectives

The objective of this research, shown in Figure 1.1, is to analyze rain attenuation and rain intensity data over 3 years period using the statistical analysis approach. Results of analysis will be used to design the Ku-band satellite system especially for Southeast Asia and will develop the general prediction model.

In this study, almost 24-year-data from four radiometers and four rain gauges in 1) Bangkok and 2) Si-racha Thailand, 3) Singapore, and 4) Bundung, Indonesia were analyzed as well as 2-year-data from two Beacon receivers at Si-racha and Songkla were also performed.

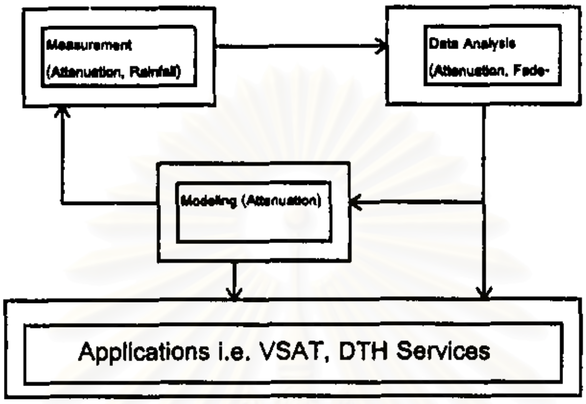

Figure 1.1 The proposed rain attenuation studies including Measurement, Data Analysis, Modeling, Applications such as VSAT, DTH (Direct to Home) services

The objectives of the research are summarized as follows:

1) to study characteristics of rain attenuation and rainfall in Southeast Asia,
2) to collect daily data from :
    2.1 Radiometers of Canada-ASEAN Cooperation in Ku-band Propagation Measurement Program on Earth -Space Path since 1992,
    2.2 Beacon receiver of The Communications Authority of Thailand since 1997,
3) to analysis rain attenuation and rain intensity data to obtain:
    - Yearly and Monthly Attenuation Distributions,
    - Worst Month Attenuation Distribution,
    - Diversity Attenuation Distribution,
    - Yearly and Monthly Rain Intensity Distribution,
    - Fade Duration Statistics,
    - Diurnal Variations of Rain Attenuation.

4) to develop the statistical models for predicting rain attenuation which are suitable for the Ku-band satellite communication system in Southeast Asia.

1.4 Methodology

The method of this research mainly relies on the measurement and data analysis. The statistical analysis both a descriptive and an inferential methods are mainly used in this research. The total measured attenuation and rain intensity data at five locations over twenty-four years are analyzed to obtain the statistical characteristics of rain attenuation and rain intensity in Southeast Asia.

1.5 Scope of Research

This research is mainly focused at 12 GHz frequencies for satellite communication applications in Southeast Asia located in ITU-R zone N and the ITU-R zone P. More cautions must be considered when the results are applied to other frequencies and other regions.

The duration of this research is about four years. The total 26 years of data to be analyzed consists of 12 years for the radiometer data, 12 years for rain intensity data, and 2 years for beacon data. Due to the natural phenomena of rainfall varies from year-to-year, and the analysis were used data collected during 1992 - 1995 and 1997, results of this study is more acceptable in those periods.

The benefits of this research are :

1) to understand characteristics of rain attenuation and rain intensity in Southeast Asia,
2) to analyze long-term and short-term attenuation and rain intensity data,
3) to develop the statistical model to predict rain attenuation for Southeast Asia,
4) to enhance the design of the Ku-band satellite communication in Southeast Asia more efficiently and cost-effectively.

1.6 Dissertation Outlines

This dissertation is composed of ten chapters outlined as below.

Chapter 1 describes the background of the research including problems of the design of the Ku-band earth-satellite link in Southeast Asia, problems of rain attenuation studies in Southeast Asia, objectives of the research, and research methodology.

Chapter 2 reviews the climate in the tropics and in Southeast Asia. Rainfall characteristics in the tropics and in Southeast Asia as well as rain intensity and rain attenuation prediction are presented. Reviews of rain attenuation studies both theoretical and experimental studies in the tropics and in Southeast Asia are described and compared with rain attenuation and rain intensity prediction models.

Chapter 3 describes rain attenuation measurement methods for this research and the radiometric and the beacon measurement systems used to study rain attenuation and rain intensity in Southeast Asia. Measurement limitations of the radiometer method, the beacon method, and rain gauge measurement are presented.

Chapter 4 presents statistical analysis of rain intensity measured at four locations in Southeast Asia. It includes annual and monthly cumulative rain intensity distributions, year-to-year variations, seasonal and diurnal variations, and rain intensity duration statistics. Measured data are used to obtain statistical distribution and compared among various rain intensity prediction models.

Chapter 5 presents statistics of rain attenuation along earth-satellite paths in Southeast Asia. Analytical analysis includes annual and monthly cumulative distributions, worst-month distribution, year-to-year variations and seasonal variations. Data are analyzed to obtain statistical distribution that most represents the measured data, and results are compared among various rain attenuation prediction models.

Chapter 6 describes and analyzes the joint cumulative (diversity) distributions of rain attenuation in Bangkok and Si-racha, Thailand. Data are analyzed to obtain the site diversity performance, improvement factor, diversity gain, and compared with the ITU-R model.

Chapter 7 presents analytical results of fade duration statistics in Southeast Asia over a three year period. The empirical model predicting fade duration distribution which is useful for the design of the Ku-band satellite communication in Southeast Asia is also presented.

Chapter 8 describes analytical studies of the diurnal variation of rain attenuation and rainfall statistics in Southeast Asia. Results of analysis including conditional probability of rain attenuation and rainfall, year-to-year variation, site-to-site variation, 2-hours cumulative distributions, are useful to develop the statistical model.

Chapter 9 presents a statistical model to predict rain attenuation distribution in any hour interval(s) of a day using the knowledge of one-hour rainfall statistic and an annual cumulative attenuation distribution. Results of the prediction are verified by the measured data over three years in Southeast Asia. The proposed general prediction method is initiated to predict the diurnal variation of rain attenuation in Southeast Asia and other regions.

Chapter 10 describes conclusions and recommendations of this dissertation.